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What features of educational interventions lead to competence in aseptic insertion and maintenance of CV catheters in acute care? BEME Guide No. 15

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Abstract

Background: Up to 6000 patients per year in England acquire a central venous catheter (CVC)-related bloodstream infection (Shapey et al. 2008). Implementation of Department of Health guidelines through educational interventions has resulted in significant and sustained reductions in CVC-related blood stream infections (Pronovost et al. 2002), and cost (Hu et al. 2004).

Aim: This review aimed to determine the features of structured educational interventions that impact on competence in aseptic insertion technique and maintenance of CV catheters by healthcare workers.

Methods: We looked at changes in infection control behaviour of healthcare workers, and considered changes in service delivery and the clinical welfare of patients involved, provided they were related directly to the delivery method of the educational intervention.

Results: A total of 9968 articles were reviewed, of which 47 articles met the inclusion criteria.

Conclusions: Findings suggest implications for practice: First, educational interventions appear to have the most prolonged and profound effect when used in conjunction with audit, feedback, and availability of new clinical supplies consistent with the content of the education provided. Second, educational interventions will have a greater impact if baseline compliance to best practice is low. Third, repeated sessions, fed into daily practice, using practical participation appear to have a small, additional effect on practice change when compared to education alone. Active involvement from healthcare staff, in conjunction with the provision of formal responsibilities and motivation for change, may change healthcare worker practice.

Introduction

Intact skin is an effective barrier to the ingress of pathogenic microorganisms, yet the necessities of modern healthcare have increased the reliance on indwelling intravascular devices. These devices, which breach the skin defence, can cause tissue damage and leave a foreign body *in situ*, thereby increasing the risk of infection for patients. Intravascular devices are used for nutritional support, fluid replacement, drug administration, monitoring and in renal replacement therapy. Central venous catheters, also referred to as CVCs, are intravascular devices whose tips terminate in a great vessel. They are almost ubiquitous in patients requiring critical care (Eggimann 2007a, b) and are also increasingly common outside the intensive environment and in the community (Woodrow 2002).

In the UK, approximately 200,000 CVCs are inserted each year (Worthington & Elliott 2005). The National Survey of nosocomial blood stream infections completed in 2002 recorded over 10,000 episodes of bacteraemia, with a mean rate of 0.6 bacteraemia per 1000 patient days (Health Protection Agency). In this survey, CVCs were the commonest

Practice points

- Educational interventions appear to have the most prolonged and profound effect when used in conjunction with audit, feedback and availability of new clinical supplies consistent with the content of the education provided.
- Educational interventions will have a greater impact if baseline compliance to best-practice is low.
- Repeated sessions, fed into daily practice, using practical participation (such as the use of demonstrations, video education, use of simulator or self-study materials) appears to have a small, additional effect on practice change when compared to education alone.
- Active involvement from healthcare staff, in conjunction with provision of formal responsibilities and motivation for change, may change healthcare worker practice.
- Dissemination of information through peers or higher management may have a small effect on practice change.

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source of hospital-acquired bacteraemia. It is estimated by Shapey et al. (2008) that 6000 patients per year in England acquire a catheter-related blood-stream infection (CRBSI). 70% of all healthcare associated infections in a recent study were primary blood stream infections and nearly half of these were related to CVCs (Smyth et al. 2008).

In the USA, published rates of CRBSI vary in the intensive care setting from 1.0 to 5.6 per 1000 catheter days, and outside critical care from 0.5 to 2.04 per 1000 catheter days (Pronovost et al. 2006). Although bloodstream infection is the most serious infectious sequelae of CVC insertion, other forms of infection are also common, yet are subject to less national surveillance and scrutiny, such as skin and soft tissue infections of the exit site or tunnel. Risk factors for CRBSI include patient factors such as malnutrition (Curtis 2008), poor skin integrity, immunosuppression and existing infection (Ranasinghe et al. 2008), as well as device factors; location of device, number of lumen, type of catheter, duration of placement and the type of dressing (Maki et al. 2006; Ranasinghe et al. 2008).

Healthcare worker variables are also significant, such as insertion technique and nurse-to-patient ratio. The organisms causing CRBSI vary according to the clinical setting but in all instances Gram-positive organisms predominate. Coagulase-negative staphylococci (CoNS) are the commonest organism associated with intravascular device infection and these organisms have been increasingly reported as the cause of blood stream infections in the UK (Health Protection Agency).

CoNS are the causative organism of CRBSI in 39% of cases and *Staphylococcus aureus* in 26% with Gram-negative bacilli and *Candida spp* in 14% and 11%, respectively (Woodrow 2002). The organisms gain entry to the catheter via a number of routes, most often from colonisation of the skin at the exit site or from colonisation/contamination of the catheter hub or the line access device. The organisms colonising these sites may have originated from the patient's own bacterial flora or may be introduced to the site on the hands of healthcare workers during insertion or catheter care (Fletcher & Bodenham 1999). Rarely, the infuscate can become contaminated giving rise to infection; in these situations, outbreaks have occurred (Goldmann & Pier 1993). It is also possible for the catheter to become infected as a consequence of bacteraemia from a focus distant to the device (Elliott 1988). Interaction between the organism and the catheter surface involves a series of interrelated steps including adherence, persistence and dissemination. *In vitro* the attachment of CoNS to the catheter materials occurs rapidly (Peters et al. 1982).

The *in vivo* situation is more complex as shortly after insertion and the catheter is coated with serum and tissue proteins, which may increase the adhesion of specific organisms. The persistence of CoNS on catheters following attachment has been attributed to the production of extracellular polysaccharide by the organism. This biofilm coating provides not only physical protection but may also have immunomodulating properties to protect the organism from host defences (Riber et al. 1995). Apart from some exit site infections, characterised by erythema and purulent discharge, the clinical diagnosis of CRBSI can be difficult. Clinical signs have a poor correlation with confirmed CRBSI and the diagnosis often relies on the occurrence of a systemic inflammatory response in the presence of an intravascular device with no other focus for infection.

Although a consequence of modern healthcare, CRBSI represent a considerable burden on morbidity and mortality. Warren et al. (2006b) demonstrated an increased length of stay in intensive care attributable to CRBSI of 2.41 days and in hospital of 7.54 days. Although direct mortality figures for CRBSI are contentious, unadjusted mortality in the same study was significantly higher in the CRBSI patients than in controls (51% *vs.* 28%; Warren et al. 2006). As pathogens acquire resistance mechanisms and multiply, resistant organisms become more prevalent (Health Protection Agency), and therefore morbidity and mortality are likely to increase, as will the cost. Many nosocomial infections are preventable and there are clear, evidence-based, guidelines published to optimise the care of patients who need central lines, designed to minimise the risk of infection (EPIC, Centers for Disease Control and Prevention, 2002). These guidelines include the use of maximal sterile barrier precautions during insertion, hand decontamination, use of 2% alcoholic chlorhexidine for skin antisepsis, use of transparent semi-permeable dressings and regular inspection of the insertion site. Implementation of these guidelines has resulted in significant and sustained reductions in CRBSI (Pronovost et al. 2006), and cost (Hu et al. 2004). As a result, both the Department of Health in the UK and the Institute for Healthcare Improvement in the USA have made the prevention of CRBSI as the key elements of their Saving Lives and 100,000 Lives campaigns, respectively.

In recent years, guidance documents and legislation have been generated by the Department of Health to support the development and practice of infection prevention and control in the NHS (Department of Health 1995, 2002, 2003, 2005, 2006). Prior to these initiatives, the most significant change was the publication of the Cooke report in 1995 (Department of Health 1995). This report, which revised earlier guidance, was a milestone in the organisation of infection control in hospitals and strengthened the surveillance of HCAI. Although this report did not directly address the issue of central line insertion and care, it provided a solid basis for the routine collection of infection surveillance data in hospitals. The date of publication of this report was established as the boundary of the search in the current review, as publications prior to this date are unlikely to reflect the current practice in infection prevention; and including earlier studies may affect the generalisability of the results of the review and subsequent transference of these results into practice.

This systematic review aims to inform medical and healthcare professionals, trainers, educationalists and educational researchers on the most effective features of educational interventions that lead to competence in aseptic insertion and maintenance of CVCs in acute care.

Previous reviews (Gorman et al. 1998; Cheater et al. 2006; O'Brien et al. 1998; Jamtvedt et al. 2006; Farmer et al. 2008) have focused on specific educational interventions, such as the use of printed educational materials (PEM; Farmer et al. 2008), audit and feedback (Jamdveldt et al. 2006) and reminders (Gorman et al. 1998) with no specific healthcare worker or sector target population. This review aims to address a specific

proportion of the healthcare sector, healthcare workers responsible for the insertion and maintenance of CVCs. It aims to be a focused attempt to unravel the most effective components of educational interventions in determining behavioural change in this subset of healthcare workers.

The majority of healthcare professionals regularly participate in continuing healthcare education to improve attitudes, knowledge, skill base or behaviour. Doctors spend on average, between 1 and 3 weeks a year attending educational meetings (Goulet et al. 1998; Frank et al. 2000; Nylenna & Aasland 2000). In addition to the educational meetings, healthcare professionals also utilise other educational means to improve their practice and ultimately enhance the patient outcomes. Although there are many ways by which individuals develop as professionals, such as reading of the scientific journals, accessing of web resources, following of national guidelines and attending scientific conferences, there is little consistent evidence to demonstrate how healthcare professionals' behaviour is influenced by educational delivery (Fingerhut et al. 2005).

Despite this inconsistency, educational interventions are a frequently used, costly and core method of dissemination of new knowledge within acute healthcare.

Arguably, it can be difficult not only to measure the impact of different educational interventions but also to measure the impact of each educational intervention on each occasion it is used (Grimshaw et al. 2004). Variation in selection and reporting of study design, outcome measures, healthcare professional characteristics and content and delivery of educational interventions themselves have led to difficulties in dissemination and comparison of results, notably found by both Davis et al. (1995) and Oxman et al. (1995), whilst systematically reviewing the available evidence for continuing medical education.

These limitations aside, findings, both from primary research and systematic reviews, suggest that some interventions are the most effective at evoking change than others (Davis et al. 1995; Oxman et al. 1995), such as interventions guided and supported by patients and those using reminders. Dissemination of knowledge through peers or 'opinion leaders' has also been found to be effective, a process known as 'academic detailing' (also supported by Lomas et al. 1991). The notion of academic detailing has been shown to lead to long term, significant and sustained alterations in healthcare professionals' behaviour (Avorn & Soumerai 1983; Schaffner et al. 1983; Ray et al. 1985, 1986; Everitt et al. 1990; Lomas et al. 1991), providing that concurrent measures are introduced to ensure an applicable atmosphere for the adoption of new practice (Rogers 1983).

The results from systematic reviews investigating education with no additional interventions were found to be inconclusive (Davis et al. 1995; Oxman et al. 1995). Without reinforcement, formal educational conferences and activities including role playing and peer discussion were found to have only a small impact on altering behavioural patterns; a sobering fact when considering that (by self-report) time spent by healthcare professionals attending such educational meetings, which are often mandatory, is second only to time spent reading (Frank 2000).

There has been some work looking at the effects of educational interventions with regards to clinical practice. Research into the use of PEM indicates that their value as educational tools is varied: a positive impact on clinical practice has been shown using PEM to disseminate national guidelines (Black & Hutchings 2002) – providing environmental factors upon implementation were conducive to change – yet a systematic review investigating the effect of PEM showed only a small effect compared to no intervention (Freemantle et al. 1997). It has been argued that PEM have value as educational tools when disseminating guidelines when such proposals do not require prior knowledge or skills, are grounded in evidence, are easily implemented within the work environment, and do not contradict values of the professionals involved (Grol et al. 1998; Burgers et al. 2003). Yet they may still reach a ceiling level with their effect.

A less time consuming, more widely used subset of education is provision of feedback to healthcare professionals. The effects of feedback have been found to be beneficial in changing behaviour (Eisenberg 1986; McPhee et al. 1989; Kroenke et al. 1990; Manheim et al. 1990; Frazier et al. 1991; Billi et al. 1992) but have not been well researched in terms of effect on patient outcomes. In other studies, feedback has been shown to have little or no effect on physicians' practices (Lomas et al. 1991). The discrepancies between such findings suggest that feedback should be used in conjunction with other interventions to impact on healthcare professionals' behaviour and ultimately patient outcomes. This reinforces a recurring theme throughout the literature: multiple approach educational interventions appear to be most effective at changing behaviour. Fox et al. (1989) identified that learning and change take place through a series of 'impactors' or learning resources, thus such interventions should be individually tailored to specific problems, identified through observation of care practices and informed by local policy, and should be grounded in observational results and standardised measures.

This systematic review is needed to identify specific areas of educational change, with the aim of identifying the most effective method of changing practice related to the aseptic insertion and maintenance of CVCs. This review aims to collate the best available evidence base in order to allow those managing education programmes to add consistency to the provision of their education delivery to ultimately produce significant and sustained reductions in CRBSI.

Objectives

The objective of this review was to determine individual features of educational interventions that impact on competence in aseptic insertion technique and maintenance of CVCs by healthcare workers. To evaluate this, we looked at changes in infection control behaviour of healthcare professionals, and considered changes in the clinical welfare of patients involved and in service delivery (where appropriate), provided they could be related directly to the delivery method of the educational intervention. We considered all types of educational intervention involving healthcare professionals responsible for the insertion and maintenance of CVCs, as detailed below.

Review question

Following in-group discussion and feedback from the BEME steering committee, we addressed the following review question:

What features of educational interventions lead to competence in aseptic insertion and maintenance of CVCs in acute care settings?

In addition, we also explored the following questions:

- What are the effects of individual features of educational interventions on the skills of healthcare professionals and on the institutions in which they work?
- What characterises the educational interventions that have been described?
- What are the methodological strengths and weaknesses of the reported studies?
- What are the implications of this review for service delivery, the teacher or trainer, the medical education researcher and for ongoing research in this area?

Review methodology

Group formation

A topic review group (TRG) was formed comprising of members of the Evidence-based Practice Research Centre (EPRC) at Edge Hill University, Mersey Deanery NHS NorthWest and the Royal Liverpool University Hospital. The collaboration between the EPRC, which is primarily concerned with advancing evidence-based practice through education, research and development, and these healthcare providers, whose primary aims are to assist the new Strategic Health Authority to create world-class health and healthcare systems in the North West of England, was selected to maximise expertise in both educational research methodology and practising clinical experience. The TRG consisted of two practising clinicians, and two research active members of the University staff.

Pilot process

In order to prepare for the BEME systematic review, a pilot process was undertaken. This was intended to determine the scope of the review, size of background literature, to refine the review question and to determine if adaptation of the BEME Coding Sheet (www.bemecollaboration.org/) would be suitable for use in the review.

Preliminary literature search

A scoping literature search was carried out to determine the size of background literature pertaining to the review topic and to develop a potential, encompassing search strategy for use in the final electronic literature searches.

This search was undertaken in July 2008, across Medline. Medline was chosen as the TRG expected that Medline would have the largest body of literature relating to CVCs and the most relevant publications. The pilot Medline search strategy is summarised on the BEME website (www.bemecollaboration.org). Ovid Medline was used to determine MeSH search terms, and subject headings of relevant articles were examined to further develop the search strategy.

Total of 6035 articles were retrieved as a result of this search, of which the first 200 were screened for eligibility by the lead reviewer. It was apparent that the search strategy needed refinement, and as a result, a new search strategy was established and piloted. The new strategy incorporated key phrases and additional subject headings, found by examination of relevant studies, and when piloted yielded 1702 studies. This strategy is summarised on the BEME website (www.bemecollaboration.org), and forms the basis of the search used in the final review search. Following this search, two reviewers from the project reviewed the titles and abstracts of the first 200 of the 1702 articles identified. This enabled confirmation that the lead reviewer had an appropriate balance of sensitivity and specificity for relevant evidence which could not be improved by second screening, and that this researcher alone was able to select articles for further consideration from the main search.

Preliminary pilot of coding sheet

Members of the TRG met to discuss the suitability of the BEME Coding Sheet by piloting it on a number of studies fulfilling the inclusion criteria for review (Table 1). It became apparent that there was an enormous diversity in the reporting style and details, and it therefore would not be appropriate at this stage to produce a simple categorical tool to extract data. A more comprehensive sheet was required, with more flexibility to report data as presented. A second coding sheet was devised with free text reporting boxes for this purpose. This is provided on the BEME website (www.bemecollaboration.org).

We used a quality assessment checklist to supplement the coding sheet. A tick-box method of assessment (based on Shaw et al. (in press) and adapted from Downs and Black (1998) and Kmet et al. (2004)) was adapted to incorporate various facets of the quality of study such as aims, participant selection and reporting of variables. This method of assessment yielded a quality assessment score for each paper. No study was excluded from the review based solely on quality assessment score.

The following inclusion and exclusion criteria (Table 2) were used:

Types of intervention. An educational intervention was, for the purpose of this review, defined as a structured educational process intended to increase, improve or enhance the performance of the recipients with regards to the overall health or well-being of their patients. Interventions considered for this review included, but were not limited to: courses; lectures; simulations; small group learning session(s); e-learning, curriculum-based learning; shadowing/mentoring; workshops and learning through educational material such as media, posters, handouts and other paper material.

Educational interventions considered were those designed to change staff behaviour with regards to one or more facet of

Table 1. Inclusion criteria.

Inclusion criteria	
Study design	• All study designs considered • Studies conducted and published from 1995 onwards included
Population	• Healthcare professional participants considered: specialist nurses, registered nurses, doctors, medical residents or other healthcare practitioners specifically trained in regards to insertion and maintenance of CVCs OR • Contained one or more of the above groups for which results were recorded separately
Educational intervention	• Content documentable and repeatable • Interventions run over defined time period • Interventions designed to change staff behaviour with regards to one or more facet of CVC use
Comparator	• Any, including but not limited to use of a control group, a differing educational intervention and use of differing healthcare groups
Outcome measures	• At least one outcome measure of aseptic central venous catheter maintenance/insertion practice • Measured using Kirkpatrick's hierarchy (Kirkpatrick 1967)
Setting of study	• Studies carried out in acute care settings considered
Other inclusion criteria	• Centrally placed venous catheters, regardless of mode of insertion • Catheters used for administration of fluids, medication, blood components and/or total parental nutrition

Table 2. Exclusion criteria.

Exclusion criteria	
Study design	• Reviews and systematic reviews • Studies published before 1995, or in which the study period was prior to 1995
Population	• Studies where the sole participant groups were: students, paramedics, domestic staff, dentists, dietitians, hygienists, psychologists, psychotherapists, pharmacists, physiotherapists, occupational therapists, speech therapists, managerial staff, catering staff and support staff • All studies not focusing solely on healthcare professionals, including studies using patients as sole participants • Studies where results of inclusion healthcare worker groups could not be distinguished from exclusion healthcare professional groups
Educational intervention	• Interventions focused on patient education • Interventions not educational in content, such as change in working hours or change in rates of pay
Comparator	• No exclusion criteria applied
Outcome measures	• No recorded outcome measure of aseptic central venous catheter maintenance/insertion practice
Setting of study	• Any setting other than acute care setting
Other exclusion criteria	• Non-centrally placed catheters, including urinary catheters

catheter use, including but not limited to: general asepsis, selection of catheter type, selection of insertion site, maximal sterile barrier precautions during insertion, coetaneous antisepsis, catheter site care, catheter replacement strategies and general catheter management principles.

Interventions must have been both structured and educational in their nature to be included in this review. Other interventions such as a reduction in working hours or changes in rates of pay were not considered. Feedback alone or semi-structured educational methods, such as informal teaching were not considered.

Types of participants. This review focused on the delivery of educational interventions relating to the aseptic insertion technique and maintenance of CVCs in acute settings. Participants were healthcare professionals who had a responsibility as a part of their job role to insert and/or maintain intravenous catheters under aseptic conditions, and had already been designated as 'competent' to do so by their job-role training. Participants were: specialist nurses, registered nurses, doctors, medical residents or other healthcare practitioners who had been specifically trained in regards to insertion and maintenance of CVCs (as we recognised that, country to country, these labels may have differed).

Studies where the sole participant groups were students, paramedics, domestic staff, dentists, dietitians, hygienists, psychologists, psychotherapists, pharmacists, physiotherapists, occupational therapists, speech therapists, managerial staff, catering staff and support staff were excluded from the review. Studies with participants spanning both groups were included, but only the results from the inclusion participant list were considered.

It was deemed likely that the effectiveness of educational interventions targeting patients would be different to those targeting solely healthcare professionals. Given that the differing programmes to target healthcare professionals were already diverse in their delivery, it was agreed by the TRG that adding another comparator would complicate the report. All studies that did not focus solely on healthcare professionals were therefore excluded. Where studies had focused both on educational interventions delivered to healthcare staff and those delivered to patients, only the results of the healthcare professional intervention was reported and considered. If these were not reported separately from that of the patients, the study was excluded.

Study design. Both non-comparative (audit, action-based research, case series, historical, narrative, observational and survey-based) and comparative (cross-sectional research, before and after studies, time series studies, non-randomised trials, randomised controlled trials, group randomised trials, case control trials, cohort studies and meta-analysis) research designs were considered for inclusion. General review articles and editorials were not considered, but their reference lists were scanned to check whether all relevant materials were included.

Study setting. Studies looking at the delivery of educational interventions for management and insertion of CVCs in acute care settings were considered for the review, including but not

Table 3. Kirkpatrick's Hierarchy (1967).

Level 1: Reaction This covers learner's views on the delivery and content of the educational intervention. This may take the form of verbal or written feedback immediately after the delivery of the intervention, and includes learner's views on presentation, organisation, content, teaching methods, time-tabling, materials used and quality of teaching.	Level 3: Behavioural change This relates to the transfer of principles of aseptic CVC maintenance and insertion to the workplace, such as support for change in behaviour in the workplace, or willingness of learners to apply knowledge and skills about aseptic CVC insertion and maintenance, obtained as a direct result of the delivery of the educational intervention, to their practice style.
Level 2a: Modification of attitudes and perceptions This relates to any changes in reciprocal attitudes or perceptions between participant groups. This includes any changes in perceptions or attitudes by participants towards the value and/or use of the taught approach to caring for patients, and their condition, circumstances, care and treatment.	Level 4a: Change in organisational practice This relates to wider changes in the organisation/delivery of care, attributable to the delivery of an education intervention. These changes may be financial or organisational.
Level 2b: Acquisition of knowledge and skills For knowledge, this relates to the acquisition of concepts, procedures and principles of aseptic CVC maintenance and insertion as a direct result of the delivery of the educational intervention. For skills, this relates to the acquisition of thinking/problem-solving, psychomotor and social skills linked to aseptic CVC maintenance and insertion as a direct result of the delivery of the educational intervention.	Level 4b: Benefits to patients/clients, families and communities This relates to any improvements in the health and well being of patients as a direct result of the delivery of an educational intervention. Where possible, objectively measured or self reported outcomes will be used, including but not limited to health status measures, infection incidence, duration or cure rates, mortality rates, complication rates, readmission rates, continuity of aseptic CVC care and costs to carer or patient. These outcomes will be further determined by the literature found.

limited to ICUs, haemodialysis units, transplant units, chemotherapy units, accident and emergency units, neonatal units and hospitals.

Comparators. Any comparators were considered for inclusion in the review, including but not limited to use of a control group (e.g. other hospital area/ward), a differing educational intervention and use of differing healthcare groups.

Other inclusions and exclusions. Studies relating to CVCs used for administration of fluids, medication, blood components and/or total parental nutrition were included in the review. All studies relating to centrally placed venous catheters were included, regardless of the mode of insertion or type of catheter present.

Outcome measures of the study. Only studies that used aseptic insertion site catheter maintenance/insertion as an outcome measure for effectiveness of delivery of educational intervention were considered. Effectiveness of delivery of educational interventions into maintenance/insertion of catheters used in response to infection already present was included in the review.

Assessment of outcome measures. These will be based on modified Kirkpatrick's (1967) model of hierarchical outcomes at four levels, as illustrated in Table 3. Additional predetermined or secondary outcome measures were also accepted and recorded. Kirkpatrick's hierarchy was selected to provide a more comprehensive evaluation, in order to inform this review's development. This model has been used by other BEME review groups (Issenberg et al. 2005) and, once modified, fitted the outcome measures of the review.

Search strategy

A comprehensive search was conducted to determine the body of literature pertaining to the review question across all sources relevant to healthcare education and best practice in a clinical context. This search was divided into two sections: an electronic search of relevant health and educational databases and augmentation of this search using various methods. These will be summarised in detail below.

Searching of the literature base

A comprehensive electronic search was carried out in August 2008.

In total, 16 electronic databases were searched. These were chosen to span clinical and educational databases, and are listed on the BEME website (www.bemecollaboration.org), along with the individual search strategies used for each. The initial, piloted strategy pertains to Medline, and was adapted for each database to reflect minor modifications specific to their vocabulary or search terms. Natural language terms were derived for those databases that did not recognise MeSH search headings, such as the National Research Register and Web of Science, and were based on synonyms of a combination of three relevant components - infection control, CVCs and education.

Medline records were substituted for duplicated records from other databases when identified due to their standardisation and level of detail. A total of 14,413 studies were retrieved, producing 9964 studies once de-duplicated. Only original research findings were included in the search, editorials and essays were excluded.

A two-stage process was employed to retrieve relevant articles. The lead reviewer (GC) and one other member of the review team (BS) initially screened all titles and abstracts, and eliminated all studies not relating to educational interventions for CVC insertion or maintenance. Any discrepancies were discussed with another member of the review team (JB), and a decision was reached. This resulted in 270 studies for which full text was obtained for all, 2.7% of the initial cohort.

A subsequent hand search of high-yield journals was carried out (BEME website (www.bemecollaboration.org) for full list of

journals hand searched), followed by a search of reference lists of all full-text studies, and hand search of the researcher's own files. This yielded a subsequent 43 studies, and cross-checking with the results of the electronic searching confirmed receipt of these studies in the initial electronic cohort.

These 270 full-text studies were independently reviewed by two members of the review team (GC and BS), seeking consensus from a third member (JB) when opinion as to suitability was divided. From this, 47 studies were identified as fulfilling all inclusion criteria and therefore suitable for inclusion in the review.

It cannot be said for certain that all relevant, high-quality published material was obtained through the combination of electronic searching and hand searching of journals selected as the most likely robust publishers of related material. However, knowledge within the field of infection control, together with continued monitoring of evidence bases has led us to conclude that this review will encompass as much published material as possible to answer the review question based on the best available evidence, using systematic processes.

Quality assessment

Each full-text paper was doubly read and quality assessed by two members of the review team (GC and JB) to ensure maximum consistency. Quality was assessed using a tool based on that by Shaw et al. (in press) and adapted from Downs and Black (1998) and Kmet et al. (2004) adapted for use in this review (on the BEME website; www.bemecollaboration.org). The tool is in the form of a checkbox document, and consists of 18 items. Each item is scored on a three-point Likert scale, with a score of 2 being the highest and 0 being the lowest for each item. An example of some items are as follows:

Are educational intervention(s) clearly described?	Defined and reproducible (score 2).	Partially defined, but insufficient detail to reproduce design (score 1).	Not described (score 0).
Is method of delivery of educational intervention and subsequent follow up clearly defined?	Sufficient relevant descriptive information. Reproducible criteria used to replicate intervention defined (score 2).	Poorly defined criteria or incomplete descriptive information (score 1).	No criteria/ descriptive info provided (score 0).

Quality was expressed as a score in each of the following categories: Study aims; study design and sample characteristics; data analysis, results and conclusions yielding a percentage score relating to the study. This percentage score is calculated as a fraction of 36, the maximum score possible. To ensure maximal data, no study was excluded from the review based solely on quality score, although this was considered in the analysis of studies. Inter-reviewer dispute was low, with the resolution of differing opinions by a third member of the group (BS) required on only four papers.

Coding

Each full text paper was coded by a member of the review team. A random sample of 20% of studies was doubly coded to ensure that appropriate, consistent and matching data were collected. No discrepancy was found between reviewers, thus it was deemed appropriate to singly code all. Data collected were entered into Microsoft Excel.

Review analysis

Description of studies

A total of 47 studies met the criteria for inclusion in this review. Of these, 35 were based in the USA, two each in Argentina, Sweden and Turkey and one each in the UK, France, Brazil, Italy, Japan and Mexico. 22 studies used both nurses and doctors (including postgraduate trainees) as participants, whilst 10 focused solely on doctors (Ely et al. 1999; Salemi et al. 2002; Sherertz et al. 2000; Young et al. 2000; Velmahos et al. 2004; Higuera et al. 2005; Miranda et al. 2007; Ramakrishna et al. 2005; Britt et al. 2007; Xiao et al. 2007), eight solely on nursing staff (Bjornestam et al. 2000; Crawford et al. 2000; Dinc & Erdil 2000; East & Jacoby 2005; Kennedy & Nightingale 2005; Ahlin et al. 2006; Hatler et al. 2006; Thibodeau et al. 2007), and seven on broadly defined 'healthcare staff' (Price et al. 2002; Rosenthal et al. 2003; Centers for Disease Control and Prevention 2002; Render et al. 2006; Bhutta et al. 2007; Harnage 2007; Capretti et al. 2008).

Outcome measures

A total of 25 studies measured a change in the healthcare professional's behaviour (Kirkpatrick level 3) as an outcome measure (Ely et al. 1999; Crawford et al. 2000; Dinc & Erdil 2000; Sherertz et al. 2000; Salemi et al. 2002; Rosenthal et al. 2003; Berenholtz et al. 2004; Coopersmith et al. 2004; Velmahos et al. 2004; East & Jacoby 2005; Higuera et al. 2005; Lobo et al. 2005; Ramakrishna et al. 2005; Wall et al. 2005; Ahlin et al. 2006; Render et al. 2006; Warren et al. 2006; Bhutta et al. 2007; Britt et al. 2007; Harnage, 2007; Miranda et al. 2007; Thibodeau et al. 2007; Tsuchida et al. 2007; Xiao et al. 2007; Costello et al. 2008), and 37 measured the change in patient outcomes (Kirkpatrick level 4b) as an outcome measure (Bishop-Kurylo 1998; Bjornestam et al. 2000; Dinc & Erdil 2000; Eggimann et al. 2000; Sherertz et al. 2000; Coopersmith et al. 2002; Curchoe et al. 2002; Price et al. 2002; Salemi et al. 2002; Rosenthal et al. 2003; Warren et al. 2003; Berenholtz et al. 2004; Coopersmith et al. 2004; Gnass et al. 2004; Misset et al. 2004; Warren et al. 2004; Centers for Disease Control and Prevention 2005; Frankel et al. 2005; Higuera et al. 2005; Kennedy & Nightingale 2005; Lobo et al. 2005; Wall et al. 2005; Berriel-Cass et al. 2006; Goeschel et al. 2006; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006; Schelonka et al. 2006; Warren et al. 2006; Young et al. 2006; Bhutta et al. 2007; Harnage 2007; Tsuchida et al. 2007; Yilmaz et al. 2007; Capretti et al. 2008; Costello et al. 2008; McKee et al. 2008). A total of 15 studies evaluated both change in healthcare professionals' behaviour

(Kirkpatrick level 3) and change in patient outcome (Kirkpatrick level 4b) as the outcome measures (Dinc & Erdil 2000; Sherertz et al. 2000; Salemi et al. 2002; Rosenthal et al. 2003; Berenholtz et al. 2004; Coopersmith et al. 2004; Higuera et al. 2005; Lobo et al. 2005; Wall et al. 2005; Render et al. 2006; Warren et al. 2006; Bhutta et al. 2007; Harnage, 2007; Tsuchida et al. 2007; Costello et al. 2008).

There was some variation in the outcome measures used. Of the 37 studies measuring change in patient outcomes, 29 used infection rates per 1000 CVC days as outcome measures. The remaining studies used measures such as infection rates per 100 parenteral nutrition days (Kennedy & Nightingale 2005), comparison of infection rates per 1000 CVC days between intervention and control groups (Higuera et al. 2005), number of CRBSI cases pre-and post-intervention (Harnage 2007), country-wide infection percentile values (Goeschel et al. 2006), microbial colonisation rates (Dinc & Erdil 2000), frequency and rates of bacteraemia present (Bjornestam et al. 2000), CRBSI rates per 100 patient months (Price et al. 2002) and time between onset of CRBSI occurrences (Gnass et al. 2004).

Of the 25 studies measuring the healthcare professionals' behaviour, two relied on self-reporting of behavioural change (Ely et al. 1999; Ahlin et al. 2006). A total of 14 studies used compliance with policy as an outcome measure (Sherertz et al. 2000; Salemi et al. 2002; Coopersmith et al. 2004; Higuera et al. 2005; Render et al. 2006; Warren et al. 2006a; Bhutta et al. 2007; Harnage 2007; Miranda et al. 2007; Xiao et al. 2007; Costello et al. 2008), and 8 studies used improvement in observed practice as an outcome measure (Crawford et al. 2000; Miranda et al. 2007; Velmahos et al. 2004; East & Jacoby 2005; Lobo et al. 2005; Ramakrishna et al. 2005; Warren et al. 2006a; Britt et al. 2007; Thibodeau et al. 2007; Tsuchida et al. 2007). Two studies reported no behavioural change attributed to education (Wall et al. 2005; Rosenthal et al. 2003).

Educational delivery

The format of the education varied between studies, creating eight groups of intervention:

- Multimodal education with a demonstration – seven studies (Ely et al. 1999; Eggimann et al. 2000; Sherertz et al. 2000; Curchoe et al. 2002; Ahlin et al. 2006; Harnage 2007; Costello et al. 2008).
- Multimodal education with no demonstration – nine studies (Bishop-Kurylo 1998; Bjornestam et al. 2000; Centers for Disease Control and Prevention 2005; Higuera et al. 2005; Lobo et al. 2005; Hatler et al. 2006, Pronovost et al. 2006; Render et al. 2006; Thibodeau et al. 2007).
- Self-study – two studies (East & Jacoby 2005; Wall et al. 2005).
- Multimodal education with a simulator – four studies (Velmahos et al. 2004; Ramakrishna et al. 2005; Britt et al. 2007; Miranda et al. 2007).
- Multimodal education with a video – five studies (Salemi et al. 2002; Frankel et al. 2005; Schelonka et al. 2006; Bhutta et al. 2007; Xiao et al. 2007).
- Multimodal education with demonstration, self-study module and behavioural intervention – two studies (Coopersmith et al. 2004; Kennedy & Nightingale 2005).
- Multimodal education with self-study module – 10 studies (Crawford et al. 2000; Dinc & Erdil 2000; Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006a; Berenholtz et al. 2004; Tsuchida et al. 2007; Yilmaz et al. 2007; McKee et al. 2008).
- Mode of delivery of education not specified – eight studies (Price et al. 2002; Rosenthal et al. 2003; Gnass et al. 2004; Misset et al. 2004; Berriel-Cass et al. 2006; Goeschel et al. 2006; Young et al. 2006; Capretti et al. 2008).
- Ten studies also used other interventions in addition to education, such as the use of a bundle (including a checklist) (Frankel et al. 2005; Wall et al. 2005; Berriel-Cass et al. 2006, Pronovost et al. 2006; McKee et al. 2008), a stepwise intervention (Bhutta et al. 2007), or other additional interventions (Bishop-Kurylo 1998; Rosenthal et al. 2003; Tsuchida et al. 2007; Lobo et al. 2005).

Included studies are summarised in Table 4.

Effects of interventions

Educational intervention 1: Education, multimodal with demonstration

There were seven studies that investigated the effect of multimodal education with demonstration, with eight comparative groups (Curchoe et al. 2002). Of these, four measured behavioural change in healthcare professionals (Kirkpatrick level 3) (Ely et al. 1999; Sherertz et al. 2000; Ahlin et al. 2006; Costello et al. 2008), and five measured change in patient or organisational outcome additionally (Kirkpatrick level 4b) (Eggimann et al. 2000; Sherertz et al. 2000; Curchoe et al. 2002; Harnage 2007; Costello et al. 2008). Three studies used both doctors and nurses as participants (Eggimann et al. 2000; Curchoe et al. 2002; Costello et al. 2008), one used nurses as a sole participant group (Ahlin et al. 2006), one used a multi-disciplinary participant group (Harnage et al. 2007), and two used doctors as a sole participant group (Ely et al. 1999; Sherertz et al. 2000).

All educational interventions contained the following components: education of staff, followed by demonstrations. Education of staff took several forms: Three studies specified classes (Ely et al. 1999; Sherertz et al. 2000; Ahlin et al. 2006), two studies specified presentations (Eggimann et al. 2000; Costello et al. 2008), two specified in-service training (Hatler et al. 2006; Eggimann et al. 2000), one specified the use of posters (Curchoe et al. 2002), and another the use of educational cards (Hatler et al. 2007) and handouts (Costello et al. 2008).

Demonstrations are described as practical (Ely et al. 1999; Sherertz et al. 2000; Curchoe et al. 2002; Ahlin et al. 2006; Harnage et al. 2007; Costello et al. 2008) using mannequins and real patients.

Three studies also contained other components, in addition to education (Ahlin et al. 2006; Harnage et al. 2007; Costello et al. 2008). Other components of the interventions included: bundle kits (Costello et al. 2008), change in supplies

Table 4. Summary of included studies.

Reference	Study period	Country of study	Study setting	Type of intervention	Participant group	Kirkpatrick level	Quality score (%)
Ahlin et al. 2006	2002–2003 (12 months)	Sweden	1 Haematology unit	Education, multimodal with demonstration	Registered nurses	3	81
Berenholtz et al. 2004	1998–2002 (60 months)	USA	1 Surgical ICU	Education, multimodal without demonstration. Self study module	Physicians, fellows, anaesthetists, surgery residents, pharmacists and nurses	3 and 4b	75
Berriel-Cass et al. 2006	2004–2006 (30 months)	USA	1 Medical ICU; 1 surgical ICU; 1 cardiac ICU; 1 cardiovascular ICU	Not specified	Physicians and nurses	4b	39
Bhutta et al. 2007	1998–2005 (60 months)	USA	1 Paediatric ICU	Education, multimodal with video	Not specified	3 and 4b	60
Bishop-Kurylo 1998	1995–1997 (26 months)	USA	1 Neonatal ICU	Education, multimodal without demonstration	Physicians, nurse practitioners and staff nurses	4b	21
Bjornestam et al. 2000	1995 (12 months)	Sweden	Children's hospital (intervention hospital wide)	Education, multimodal with demonstration	Registered nurses	4b	76
Britt et al. 2007	2005–2007 (24 months)	USA	Department of surgery	Education, multimodal with simulator	Surgical interns	3	56
Capretti et al. 2008	2003–2006 (34 months)	Italy	1 Neonatal ICU	Not specified	Not specified	4b	85
Centres for Disease Control and Prevention 2002	April 2001–March 2005 (48 months)	USA	42 Hospitals with 69 ICUs	Education, multimodal with demonstration	Not specified	4b	48
Coopersmith et al. 2004	1998–2002 (32 months)	USA	1 surgical ICU	Education, multimodal with demonstration. Self study module. Behavioural intervention	Physicians and nurses	3 and 4b	75
Coopersmith et al. 2002	1998–2000 (36 months)	USA	1 surgical ICU	Education, multimodal without demonstration. Self study module	Physicians and nurses	4b	100
Costello et al. 2008	2004–2006 (31 months)	USA	1 paediatric cardiac ICU	Education, multimodal with demonstration	Nurses, physicians and healthcare staff	3 and 4b	84
Crawford et al. 2000	1995–1999	USA	Tertiary care hospital (department not specified)	Education, multimodal without demonstration. Self study module	Registered nurses	3	31
Curchoe et al. 2002	2000–2001 (12 months)	USA	1 medical-surgical ICU	Education, multimodal with demonstration	Nursing staff and 1st year residents	4b	40
Dinc & Erdil 2000	1996–1997 (12 months)	Turkey	1 surgical ICU	Education, multimodal without demonstration. Self study module	Registered nurses	3 and 4b	88
East & Jacoby 2005	2002–2003 (7 months)	USA	1 Cardiovascular ICU	Self study	Registered nurses	3	86
Eggimann et al. 2000	1995–1997 (25 months)	Switzerland	1 Medical ICU	Education, multimodal with demonstration	Physicians, nurses and nursing assistants	4b	88
Ely et al. 1999	Not specified	USA	1 Medical centre	Education, multimodal with demonstration	Incoming house officers	3	57
Frankel et al. 2005	2001–2003 (24 months)	USA	1 Surgical ICU	Education, multimodal with video	2nd year residents and nurses	4b	54
Gnass et al. 2004	1997–2001 (57 months)	Argentina	1 Medical-surgical ICU	Not specified	Physicians and nurses	4b	32
Goeschel et al. 2006	2003–2005	USA	77 Hospitals with 127 ICUs	Not specified	First year residents and nursing staff	4b	40
Harnage 2007	2006–2007 (15 months)	USA	1 Medical-surgical ICU; 1 trauma-neuro ICU	Education, multimodal with demonstration	Not specified	3 and 4b	50
Hatler et al. 2006	2003–2004	USA	1 Medical ICU	Education, multimodal without demonstration	Registered nurses	4b	54
Higuera et al. 2005	2002–2003 (11 months)	Mexico	1 Mixed ICU; 1 neurosurgical ICU	Education, multimodal without demonstration	Surgical interns	3 and 4b	89

(*continued*)

Table 4. Continued.

Reference	Study period	Country of study	Study setting	Type of intervention	Participant group	Kirkpatrick level	Quality score (%)
Kennedy & Nightingale 2005	1999–2001 (approx. 24 months)	UK	University hospital, all adult areas	Education, multimodal with demonstration. Self study module. Behavioural intervention	Physicians, nurses and untrained nursing staff (plus university based student nurses, excluded from analysis)	4b	82
Lobo et al. 2005	2002 (12 months)	Brazil	1 Medical ICU	Education, multimodal without demonstration	Medical residents and nurses	3 and 4b	100
McKee et al. 2008	2001–2006 (61 months)	USA	1 Paediatric ICU	Education, multimodal without demonstration. Self study module	Physicians and nurses	4b	81
Miranda et al. 2007	2004–2005 (4 months)	USA	Simulation laboratory	Education, multimodal with simulator	Internal medical residents	3	93
Misset et al. 2004	1995–2000 (60 months)	France	1 Mixed ICU	Not specified	Physicians and nurses	4b	92
Price et al. 2002	1999–2002 (48 months)	USA	1 Outpatient haemodialysis centre	Not specified	'Staff'	4b	
Pronovost et al. 2006	2003–2006 (29 months)	USA	103 ICUs	Education, multimodal without demonstration	Physicians and nurses	4b	68
Ramakrishna et al. 2005	2000–2002 (23 months)	USA	Cardiac catheterisation laboratory	Education, multimodal with simulator	Internal medical residents	3	100
Render et al. 2006	2004–2006 (36 months)	USA	9 Hospitals with 21 ICUs	Education, multimodal without demonstration	'Healthcare workers'	3 and 4b	76
Rosenthal et al. 2003	1999–2001 (27 months)	Argentina	2 Mixed ICUs; 2 coronary ICUs	Not specified	'Healthcare workers'	3 and 4b	73
Salemi et al. 2002	1999–2000 (17 months)	USA	1 Medical-surgical ICU; 1 cardiac care unit	Education, multimodal with video	Physicians	3 and 4b	61
Schelonka et al. 2006	1999–2004 (50 months)	USA	1 Neonatal ICU	Education, multimodal with video	Physicians and nurses	4b	100
Sherertz et al. 2000	1995–1997 (24 months)	USA	6 ICUs; 1 step down unit	Education, multimodal with demonstration	1st year residents (and medical students-results excluded)	3 and 4b	61
Thibodeau et al. 2007	2004–2005 (14 months)	USA	Medical Centre, no more details provided	Education, multimodal without demonstration	Registered nurses	3	68
Tsuchida et al. 2007	2000–2002 (32 months)	Japan	1 Mixed ICU	Education, multimodal without demonstration. Self study module	Physicians and nurses	3 and 4b	68
Velmahos et al. 2004	2001 (2 months)	USA	Surgical skills laboratory	Education, multimodal with simulator	Surgical interns	3	100
Wall et al. 2005	2002–2004 (58 months)	USA	1 Medical ICU	Self study	Physicians and nurses	3 and 4b	54
Warren et al. 2003	1998–2000	USA	1 Medical ICU; 1 surgical ICU	Education, multimodal without demonstration. Self study module	Physicians and nurses	4b	96
Warren et al. 2004	2000–2003 (48 months)	USA	1 Medical ICU	Education, multimodal without demonstration. Self study module	Physicians and nurses	4b	89
Warren et al. 2006	2002–2003 (24 months)	USA	5 Medical ICUs; 6 surgical ICUs; 2 mixed ICUs	Education, multimodal without demonstration. Self study module	Physicians and nurses	3 and 4b	86
Xiao et al. 2007	2004–2005 (12 months)	USA	Urban trauma centre	Education, multimodal with video	Surgical and emergency medicine residents	3	100
Yilmaz et al. 2007	2003–2004 (13 months)	Turkey	Patients with CVC (excluding neonatal) at Technical Medical School	Education, multimodal without demonstration. Self-study module	Physicians, interns and nurses	4b	88
Young et al. 2006	2001–2003 (24 months)	USA	1 Mixed ICU	Not specified	Medical and surgical residents	4b	57

(Harnage et al. 2007; Costello et al. 2008) and feedback (Costello et al. 2008).

Kirkpatrick level 3. Changes in behaviour were reported via the following outcome: change in adherence or compliance with policy (Ely et al. 1999; Sherertz et al. 2000; Ahlin et al. 2006; Costello et al. 2008).

Statistically significant behavioural changes occurred in three of the four studies (Ely et al. 1999; Sherertz et al. 2000; Costello et al. 2008). Accepted significance values ranged from 0.001 to 0.004. The fourth study (Ahlin et al. 2006) did not report a statistically significant change in behavioural outcome, although changes in behaviour were reported.

Duration of follow up ranged from 4 to 9 months.

Kirkpatrick level 4. Changes in organisational and patient outcome were reported via the following outcomes: Cost savings (Sherertz et al. 2000), CRBSI rates per 1000 CVC days (Eggimann et al. 2000; Sherertz et al. 2000; Curchoe et al. 2002; Costello et al. 2008), time between infections (Costello et al. 2008), and number of infection cases (Harnage et al. 2007).

Statistically significant behavioural changes occurred in three of the five studies (Sherertz et al. 2000; Curchoe et al. 2002; Costello et al. 2008). Of the four studies measuring CRBSI rate per 1000 CVC days (Eggimann et al. 2000; Sherertz et al. 2000; Curchoe et al. 2002; Costello et al. 2008), three reported statistically significant results (Sherertz et al. 2000; Curchoe et al. 2002; Costello et al. 2008). Accepted significance values ranged from 0.0003 to 0.01.

The study measuring time between infections (Costello et al. 2008) showed a statistically significant result ($p = 0.008$). The study measuring risk factors for infection (Pronovost et al. 2006) produced statistically significant results ($p = 0.01$). The study measuring number of infection cases (Harnage et al. 2007) showed no statistically significant results.

Duration of follow up ranged from 6 to 17 months, with one study reporting no data about length of follow up (Curchoe et al. 2002).

Estimated cost savings were reported by one study (Sherertz et al. 2000) at between $36,000 and $800,000.

Educational intervention 2: Education, multimodal without demonstration

There were nine studies that investigated the effect of multimodal education without demonstration, with 10 comparative groups (Center for Disease Control and Prevention 2005; Higuera et al. 2005; Render et al. 2006). Of these, three measured behavioural change in healthcare professionals (Kirkpatrick level 3) (Higuera et al. 2005; Lobo et al. 2005; Render et al. 2006), and nine measured change in patient or organisational outcome additionally (Kirkpatrick level 4b) (Bishop-Kurylo 1998; Bjornestam et al. 2000; Center for Disease Control and Prevention 2005; Higuera et al. 2005; Lobo et al. 2005; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006; Thibodeau et al. 2007). Two studies used both doctors and nurses as participants (Lobo et al. 2005; Pronovost et al. 2006), four used nurses as a sole participant group (Bjornestam et al. 2000; Hatler et al. 2006; Render et al. 2006; Thibodeau et al. 2007), two used a multi-disciplinary participant group (Bishop-Kurylo 1998; Center for Disease Control and Prevention 2005), and one used doctors as a sole participant group (Higuera et al. 2005). Three studies educated team leaders for them to disseminate findings to other team members (Bishop-Kurylo 1998; Pronovostt et al. 2006; Thibodeau et al. 2007).

All educational interventions contained the following components: education of staff using no demonstrations. Education of staff took several forms: Four studies specified classes (Bjornestam et al. 2000; Higuera et al. 2005; Lobo et al. 2005; Muto et al. 2005), two studies specified meetings (Bishop-Kurylo 1998; Render et al. 2006), one specified newsletters (Hatler et al. 2006), one specified nurse led programmes (Thibodeau et al. 2007), and one specified conference calls (Pronovost et al. 2006).

Five studies also used additional educational materials, such as posters, fact sheets and printed information (Lobo et al. 2005; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006; Thibodeau et al. 2007).

Seven studies also contained other components, in addition to education (Bishop-Kurylo 1998; Higuera et al. 2005; Lobo et al. 2005; Pronovost et al. 2006; Hatler et al. 2006; Render et al. 2006; Thibodeau et al. 2007).

Other components of the interventions included: discussions (Lobo et al. 2005; Pronovost et al. 2006; Thibodeau et al. 2007), change in supplies (Bishop-Kurylo 1998; Higuera et al. 2005; Lobo et al. 2005; Pronovost et al. 2006; Thibodeau et al. 2007) and feedback (Bishop-Kurylo 1998; Higuera et al. 2005; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006). One study used rewards as incentives (Hatler et al. 2006) and one study changed policy (Thibodeau et al. 2007).

One study used a rapid cycle approach (Hatler et al. 2006), and focused on the reduction of ventilator-acquired pneumonia in addition to CVC infection rates.

Kirkpatrick level 3. Changes in behaviour were reported via the following outcome: change in adherence or compliance with policy (Higuera et al. 2005; Lobo et al. 2005; Render et al. 2006).

Statistically significant behavioural changes occurred in two of the three studies (Higuera et al. 2005; Lobo et al. 2005). Accepted significance values ranged from 0.0000 to 0.001. The third study (Render et al. 2006) did not report a statistically significant change in behavioural outcome, although changes in behaviour were reported. Duration of follow up ranged from 8to 12 months.

Kirkpatrick level 4. Changes in organisational and patient outcome were reported via the following outcomes: Cost savings (Hatler et al. 2006), CRBSI rates per 1000 CVC days (Center for Disease Control and Prevention 2005; Higuera et al. 2005; Lobo et al. 2005; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006), risk factors for infection (Pronovost et al. 2006), bacteraemia or pathogen levels (Bjornestam et al. 2000; Lobo et al. 2005) and PICC replacement rates (Thibodeau et al. 2007).

Statistically significant behavioural changes occurred in five of the nine studies (Lobo et al. 2005; Muto et al. 2005; Pronovost et al. 2006; Render et al. 2006; Higuera et al. 2005). Of the seven studies measuring CRBSI rate per 1000 CVC days (Bishop-Kurylo 1998; Center for Disease Control and Prevention 2005; Higuera et al. 2005; Lobo et al. 2005; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006), four reported statistically significant results (Center for Disease Control and Prevention 2005; Higuera et al. 2005; Pronovost et al. 2006; Render et al. 2006). Accepted significance values ranged from 0.0001 to 0.05.

Of the two studies measuring bacteraemia or pathogen levels (Bjornestam et al. 2000; Lobo et al. 2005), one showed a statistically significant result (Lobo et al. 2005, $p = 0.02$). Bjornestam et al. 2000 showed no effect from the intervention. The study measuring risk factors for infection (Pronovost et al. 2006) produced statistically significant results ($p = 0.01$). The study measuring PICC replacement rates (Thibodeau et al. 2007) did not show statistically significant results.

Duration of follow up ranged from 8 to 18 months, with one study reporting no data about the length of follow up (Thibodeau et al. 2007).

Estimated cost savings were reported by one study (Hatler et al. 2006) at between $220,150 and $1,309,000. This study also found a reduction in rates of VAP.

Educational intervention 3: Self study

There were two studies that investigated the effects of self-study, with no comparative groups (East & Jacoby 2005; Wall et al. 2005). Of these, both measured behavioural change in healthcare professionals (Kirkpatrick level 3), and one measured change in patient outcome additionally (Kirkpatrick level 4b; Wall et al. 2005). One used nurses as the sole participant group (East & Jacoby 2005) and one used both doctors and nurses as the participant group (Wall et al. 2005).

Both educational interventions contained self-study as the main educational component, though in different forms; Wall et al. (2005) used a mandatory web-based tutorial, whilst East and Jacoby (2005) used a paper-based self-study module containing a poster and fact sheet. East and Jacoby (2005) did not use additional interventions for the duration of the study period. Wall et al. (2005) also used a standardised nursing checklist, monitoring of practice and continuous monthly audit and feedback. The effects of the education were not able to be differentiated from the additional interventions.

Kirkpatrick level 3. Statistically significant behavioural changes occurred in one study (East & Jacoby 2005) with accepted significance levels of less than 0.05. Duration of follow up ranged from between 1 and 2 months (Wall et al. 2005) to 12 months (East & Jacoby 2005).

Changes in behaviour were reported via the following outcomes: Compliance with CVC policy (East & Jacoby 2005; Wall et al. 2005) and number of CVCs inserted in femoral vein (Wall et al. 2005).

Kirkpatrick level 4. Wall et al. (2005) also measured change in patient outcome, and reported a change, but no statistically significant reported difference pre-and post-educational intervention when analysing CVC infection rates per 1000 CVC days.

Educational intervention 4: Multimodal education with a simulator

There were four studies that investigated the effect of multimodal education with a simulator, with seven comparative groups (Velmahos et al. 2004; Ramakrishna et al. 2005; Britt et al. 2007; Miranda et al. 2007). Of these, all measured behavioural change in healthcare professionals (Kirkpatrick level 3), and one measured change in patient outcome additionally (Kirkpatrick level 4b; Miranda et al. 2007). All used medical residents as a participant group.

All educational interventions contained the following components: education of procedure prior to practical component, supervised practice of CVC insertion (using artificial simulator in three studies: Velmahos et al. (2004), Britt et al. (2007) and Miranda et al. (2007), and using real patient in simulation laboratory in one study, Ramakrishna et al. (2005)) and observation or instruction during and prior to insertion. No study used additional interventions for the duration of the study period. One study used self-study materials to supplement the educational intervention (Velmahos et al. 2004). This study also used the principles of Cognitive Task Analysis as a basis for the intervention.

Kirkpatrick level 3. Statistically significant behavioural changes occurred in three of the four studies (Velmahos et al. 2004; Ramakrishna et al. 2005; Miranda et al. 2007) with accepted significance levels ranging from >0.001 to 0.05. Duration of follow up ranged from 2.5 months to 3 years.

Changes in behaviour were reported via the following outcomes: number of IJCVLPs placed over 3 years post-intervention (Ramakrishna et al. 2005), likelihood of success to perform insertion steps correctly (Velmahos et al. 2004), use of MSBP post-intervention (Miranda et al. 2007) and competence in placing central line (Britt et al. 2007).

Kirkpatrick level 4. Miranda et al. (2007) also measured change in patient outcome, and found no statistically significant difference between control and intervention groups when analysing complication rates per 1000 CVC days ($p = 0.29$).

Educational intervention 5: Education, multimodal with video

There were five studies that investigated the effect of multimodal education with video, with seven comparative groups (Xiao et al. 2007). Of these, three measured behavioural change in healthcare professionals (Kirkpatrick level 3) (Salemi et al. 2002; Bhutta et al. 2007; Xiao et al. 2007), and four measured change in patient or organisational outcome additionally (Kirkpatrick level 4b) (Salemi et al. 2002; Schelonka et al. 2006; Frankel et al. 2005; Bhutta et al. 2007). Two studies used doctors as the sole participants (Salemi et al. 2002; Xiao et al. 2007), one did not specify their participant

group (Bhutta et al. 2007), and two used doctors and nurses as a participant group (Frankel et al. 2005; Schelonka et al. 2006).

All educational interventions contained the following components: education of staff and the use of videos. Education of staff took several forms: Three studies used videos as the main means of education (Schelonka et al. 2002; Frankel et al. 2005; Xiao et al. 2007), and two studies used videos in addition to other means of education (Salemi et al. 2002; Bhutta et al. 2007). One study used paper material as a control group (Xiao et al. 2007). One study specified the use of posters (Bhutta et al. 2007), and others the use of materials such as banners, posters and flyers (Salemi et al. 2006; Bhutta et al. 2007) and handouts (Costello et al. 2008).

Four studies also contained other components, in addition to education (Schelonka et al. 2002; Frankel et al. 2005; Salemi et al. 2006; Bhutta et al. 2007). Other components of the interventions included: stepwise programme instigation (Bhutta et al. 2007), change in supplies (Frankel et al. 2005; Bhutta et al. 2007) and feedback (Schelonka et al. 2002; Salemi et al. 2006). Salemi et al. (2006) also used rewards as incentives for staff.

Kirkpatrick level 3. Changes in behaviour were reported via the following outcome: change in adherence or compliance with policy (Salemi et al. 2002; Bhutta et al. 2007; Xiao et al. 2007).

Statistically significant behavioural changes occurred in no studies, although changes in behaviour were reported. Duration of follow up ranged from 23 to 24 months.

Kirkpatrick level 4. Changes in organisational and patient outcome were reported via the following outcomes: CRBSI rates per 1000 CVC days (Schelonka et al. 2002; Frankel et al. 2005; Bhutta et al. 2007), and nosocomial infection rates per 1000 patient days (Salemi et al. 2006).

Statistically significant behavioural changes occurred in three of the four studies (Schelonka et al. 2002; Frankel et al. 2005; Bhutta et al. 2007). Of the three studies measuring CRBSI rate per 1000 CVC days, two reported statistically significant results (Frankel et al. 2005; Bhutta et al. 2007). Accepted significance values ranged from 0.0001 to 0.001.

The study measuring nosocomial infection rates (Salemi et al. 2006) showed no statistically significant results, but did show a reduction in infection rates post-intervention.

Duration of follow up ranged from 23 to 24 months, with three studies reporting no data about length of follow up (Frankel et al. 2005; Salemi et al. 2006; Xiao et al. 2007). Estimated cost savings were not reported.

Educational intervention 6: Multimodal education with demonstration and self-study

There were two studies that investigated the effect of multimodal education with demonstration and self-study (Coopersmith et al. 2004; Kennedy & Nightingale 2005). Of these, both measured behavioural change in healthcare professionals (Kirkpatrick level 3) (Coopersmith et al. 2004; Kennedy & Nightingale 2005), and both measured change in patient outcome additionally (Kirkpatrick level 4b) (Coopersmith et al. 2004; Kennedy & Nightingale 2005). Both used doctors and nurses as a participant group.

Both educational interventions contained the following components: education of healthcare staff, demonstration and self-study module. No study used additional interventions for the duration of the study period. One study used parenteral nutrition for the focus of the intervention (Kennedy & Nightingale 2005).

Kirkpatrick level 3. Statistically significant behavioural changes occurred in both studies (Coopersmith et al. 2004; Kennedy & Nightingale 2005) with accepted significance levels of between >0.001 and 0.05. Duration of follow up was 18 months.

Changes in behaviour were reported via the following outcomes: compliance in CVC site care (Coopersmith et al. 2004) and number of femoral vein insertions (Kennedy & Nightingale 2005).

Kirkpatrick level 4. Both studies looked at changes in patient or organisational outcomes (Coopersmith et al. 2004; Kennedy & Nightingale 2005) and neither found a statistically significant outcome.

Cost savings were measured in one study (Kennedy & Nightingale 2005) with reported savings of £7974, or £228 per patient.

Educational intervention 7: Multimodal education with self-study

There were 10 studies that investigated the effect of multimodal education with self-study, with 12 comparative groups (Dinc & Erdil 2000; Berenholtz et al. 2004). Of these, eight measured behavioural change in healthcare professionals (Kirkpatrick level 3) (Crawford et al. 2000; Dinc & Erdil 2000; Warren et al. 2003, 2004, 2006a; Berenholtz et al. 2004; Tsuchida et al. 2007; Yilmaz et al. 2007), and nine measured change in patient or organisational outcome additionally (Kirkpatrick level 4b) (Dinc & Erdil 2000; Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006a; Berenholtz et al. 2004; Tsuchida et al. 2007; Yilmaz et al. 2007; McKee et al. 2008). Six studies used both doctors and nurses as participants (Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006a; Yilmaz et al. 2007; McKee et al. 2008), two used nurses as a sole participant group (Crawford et al. 2000; Dinc & Erdil 2000), and one used a multi-disciplinary participant group (Berenholtz et al. 2004).

All educational interventions contained the following components: education of staff prior to self-study module and self-study module. Education of staff took several forms: five studies specified lectures (Warren et al. 2003, 2004, 2006a; Berenholtz et al. 2004; McKee et al. 2008), two studies specified classroom training (Crawford et al. 2000; Dinc & Erdil 2000), one specified demonstration (Tsuchida et al. 2007), one specified in-service training through meetings and seminars (Yilmaz et al. 2007), and one specified modular education (Coopersmith et al. 2002).

Self-study took several forms: five studies used short self-study modules, with length ranging from 9 to 20 pages

(Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006a; Yilmaz et al. 2007), two studies used web-based training modules for doctors only (Berenholtz et al. 2004; McKee et al. 2008) and three did not specify the format of self study in detail (Crawford et al. 2000; Dinc & Erdil 2000; Tsuchida et al. 2007).

A written test was required in seven studies (Coopersmith et al. 2002; Warren et al. 2003, 2004; Berenholtz et al. 2004; Yilmaz et al. 2007; McKee et al. 2008). Two studies specified a minimum score to be obtained before completion, and required re-completion of test until obtained (Warren et al. 2004; Yilmaz et al. 2007).

Eight studies also contained other components, in addition to education (Dinc & Erdil 2000; Coopersmith et al. 2002; Warren et al. 2004, 2006, 2007; Berenholtz et al. 2004; Tsuchida et al. 2007; McKee et al. 2008).

Other components of the interventions included: posters (Coopersmith et al. 2002; Warren et al. 2004, 2006; Tsuchida et al. 2007), fact sheets (Coopersmith et al. 2002; Warren et al. 2004, 2006), feedback (Coopersmith et al. 2002; Warren et al. 2003, 2004; McKee et al. 2008), bundle approaches (Berenholtz et al. 2004; McKee et al. 2008), and a promotional campaign (Warren et al. 2004).

The educational intervention used in one study (McKee et al. 2008) was based on another educational intervention (by Berenholtz et al. 2004). Both used principles of Cabana's conceptual model to ensure adherence to practice guidelines.

Kirkpatrick level 3. Changes in behaviour were reported via the following outcomes: femoral vein placements (Warren et al. 2003, 2004, 2006), compliance with policy or guidelines (Dinc & Erdil 2000; Berenholtz et al. 2004; Warren et al. 2006; Tsuchida et al. 2007), success rates (Crawford et al. 2000) and risk factors for insertion (Yilmaz et al. 2007).

Statistically significant behavioural changes occurred in three of the 10 studies (Warren et al. 2003, 2004, 2006), all measuring femoral vein placements. Accepted significance values ranged from 0.001 to 0.002. No other studies reported statistically significant changes in behavioural outcomes, although changes in behaviour were reported for most studies.

One study found no correlation between CVC infection rate and dating of insertion site or visible blood on dressings.

Duration of follow up ranged from 5 to 24 months, with two studies reporting no data about length of follow up (Crawford et al. 2000; Dinc & Erdil 2000).

Kirkpatrick level 4. Changes in organisational and patient outcome were reported via the following outcomes: Cost savings (Berenholtz et al. 2004; Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006), CRBSI rates per 1000 CVC days (Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006; Berenholtz et al. 2004; Tsuchida et al. 2007; Yilmaz et al. 2007; McKee et al. 2008), microbial colonisation rate (Dinc & Erdil 2000), time to onset of infection (Warren et al. 2003), number of isolates (Coopersmith et al. 2002; Warren et al. 2004) and arterial catheter infection rates (Yilmaz et al. 2007).

Statistically significant behavioural changes occurred in of the seven of the 10 studies (Dinc & Erdil 2000; Coopersmith et al. 2002; Warren et al. 2004, 2006a; Tsuchida et al. 2007; Yilmaz et al. 2007; McKee et al. 2008). Of the eight studies measuring CRBSI rate per 1000 CVC days (Coopersmith et al. 2002; Warren et al. 2003, 2004, 2006; Berenholtz et al. 2004; Tsuchida et al. 2007; Yilmaz et al. 2007; McKee et al. 2008), six reported statistically significant results (Coopersmith et al. 2002; Warren et al. 2004, 2006; Tsuchida et al. 2007; Yilmaz et al. 2007; McKee et al. 2008). Accepted significance values ranged from 0.001 to 0.05.

The one study measuring microbial colonisation rate (Dinc & Erdil 2000) showed a statistically significant result ($p = 0.05$). The study measuring time to onset of infection (Warren et al. 2003) produced no statistically significant results ($p = 0.7$). Neither study measuring number of isolates (Coopersmith et al. 2002; Warren et al. 2004) showed statistically significant results, and the study measuring arterial catheter infection rates (Yilmaz et al. 2007) showed a statistically significant decrease ($p = 0.001$).

Duration of follow up ranged from 5 to 24 months, with one study reporting no data about length of follow up (Dinc & Erdil 2000).

Estimated cost savings range from $336,000 to $4,358,108 (Warren et al. (2003) report $336,000 to $574,000, Warren et al. (2004) report $103,600 to $1,573,000, Warren et al. (2006) report $148,844 to $2,408,000, Berenholtz et al. (2004) report $3,111,381 to $4,358,108).

Educational intervention 8: Delivery not specified

Eight studies did not specify how the educational intervention was delivered (Price et al. 2002; Rosenthal et al. 2003; Gnass et al. 2004; Misset et al. 2004; Berriel-Cass et al. 2006; Goeschel et al. 2006; Young et al. 2006; Capretti et al. 2008).

Of these, one measured behavioural change in healthcare professionals (Kirkpatrick level 3) (Rosenthal et al. 2003), and eight measured change in patient or organisational outcome additionally (Kirkpatrick level 4b) (Price et al. 2002; Rosenthal et al. 2003; Gnass et al. 2004; Misset et al. 2004; Berriel-Cass et al. 2006; Goeschel et al. 2006; Young et al. 2006; Capretti et al. 2008).

Six studies employed multiple intervention approaches (Price et al. 2002; Rosenthal et al. 2003; Misset et al. 2004; Berriel-Cass et al. 2006; Goeschel et al. 2006; Young et al. 2006).

Kirkpatrick level 3. Statistically significant behavioural changes occurred in the only study to consider behavioural change (Rosenthal et al. 2003), measuring compliance with policy ($p = 0.001$).

Kirkpatrick level 4. Statistically significant behavioural changes occurred in of the seven of the eight studies (Price et al. 2002; Rosenthal et al. 2003; Gnass et al. 2004; Berriel-Cass et al. 2006; Goeschel et al. 2006; Young et al. 2006; Capretti et al. 2008). Accepted significance values ranged from 0.001 to 0.4.

One study reported cost savings as a result of the intervention (Young et al. 2006), who estimated these to be between $460,000 and $368,000.

Percentage reduction in infection post-intervention

Percentage reduction in infection was calculated for all studies where appropriate. This is summarised in Table 5, and shown graphically for each educational intervention group in Figure 1. Percentage reduction in infection rates (usually measured as infections per 1000 CVC days) were calculated for 31 studies (Bishop-Kurylo 1998; Eggimann et al. 2000; Sherertz et al. 2000; Coopersmith et al. 2002; Curchoe et al. 2002; Price et al. 2002; Salemi et al. 2002; Rosenthal et al. 2003; Warren et al. 2003, 2004, 2006; Berenholtz et al. 2004; Coopersmith et al. 2004; Misset et al. 2004; Centers for Disease Control and Prevention 2005; Frankel et al. 2005; Lobo et al. 2005; Wall et al. 2005; Berriel-Cass et al. 2006; Hatler et al. 2006; Pronovost et al. 2006; Render et al. 2006; Schelonka et al. 2006; Young et al. 2006; Bhutta et al. 2007; Harnage 2007; Tsuchida et al. 2007; Yilmaz et al. 2007; Capretti et al. 2008; Costello et al. 2008; McKee et al. 2008).

Reductions ranged from 18% (Coopersmith et al. 2004*)* to 100% (Misset et al. 2004; Berenholtz et al. 2004; Pronovost et al. 2006; Harnage et al. 2007).

Review discussion

The inclusion of 47 studies illustrates the growth in literature pertaining to educational interventions for infection control within acute care. We have tried to obtain all relevant information for inclusion in this review. To minimise the risk of missing relevant papers, we adopted the approach of obtaining all full text papers for any potentially relevant abstracts.

Delivery of educational interventions related to CVC care was divided into eight groups for the purpose of this review. No group seemed to have a significant impact on changes in either patient care or healthcare professionals' behaviour compared to any other; all reporting some degree of statistically significant change for both patient outcomes, change in healthcare professionals' behaviour or both. Multimodal education with self-study and demonstrations appeared to have a statistically significant effect on healthcare worker behaviour, yet no statistically significant effect on patient outcome measures. In comparison, multimodal education using video appeared to have a statistically significant effect on patient outcome measures, yet no statistically significant effect on healthcare professional's behaviour. Both of these groups contained small numbers of studies, possibly accounting for this.

The group not specifying delivery of education appeared to have consistent, statistically significant improvements on both healthcare professional's behaviour and patient outcomes, possibly due to the large number of studies using multiple-intervention approaches within that group. These results lend support to the findings of Fox et al. (1989), who stated learning occurs through a series of 'impactors', thus multiple-approach interventions are generally deemed to be most effective in changing behaviour. Previous research has indicated that the use of feedback changes behavioural patterns (Eisenberg 1986; Manheim et al. 1990), although the effect on patient outcomes has been variable. This review identified 19 studies using feedback in addition to education as a means of improving patient outcome. Percentage improvement (usually reported as infection rates per 1000 CVC days) ranged from 21% to 100%. Those studies using a mixture of educational interventions as well as feedback seemed to have the best outcome. The two studies achieving 100% reduction in infection rates both combined feedback with other interventions (the use of a bundle approach, introduction of checklists to improve adherence to compliance, use of both PEM and formal educational meetings, and reinforcement of taught principles). Interestingly, neither used demonstrations in their technique, yet both employed a 'train the trainer' approach, similar to that described by Lomas et al. 1991, termed academic detailing. Another three studies (with a high reduction in infection rates) also used these principles with the exception of checklists, PEM academic detailing and formal educational meetings. These results support the finding of Hulscher et al. (2006), that audit and feedback combined with educational materials or meetings produce statistically significant improvements in behaviour when compared with no intervention. It may be difficult to identify the most effective part of the intervention.

PEM as an educational intervention have been shown to be effective providing that no prior knowledge or skills are required, the information is grounded in evidence, the taught material is easily implemented and the content does not contradict values of healthcare professionals (Grol et al. 1998; Burgers et al. 2003). Twenty studies used PEM as a means of communicating information, either as a sole means or in conjunction with other interventions. Evidence from this review suggests that the effects of PEM cannot be isolated from the effects of other components. It is unlikely that the use of PEM alone would be an influential factor in improving behavioural patterns. This may be due to the complexity of the intended target behaviour, the lack of assessment of prior values and attitudes of healthcare professionals. Further research should be carried out to investigate the influence of prior attitudes or values on behavioural style, as improvement in infection control behaviour is a complex interaction of many factors.

Formal educational meetings, with and without demonstration, also yield mixed results when considering them in the context of this review. A wide range of percentage improvements in patient outcome are apparent within the 26 studies using formal educational meetings, ranging from 18% to 100%. Highest improvements occur when used in addition to other interventions, such as feedback, published evidence, practice opportunities and when supported by senior staff and peers. This finding supports the work of Peloso and Stakiw (2000), and again lends support to the conclusion that multiple interventions are more useful in terms of eliciting and sustaining behavioural change than single interventions (Grilli et al. 1994; Davis et al. 1995; Oxman et al. 1995).

Reminders have also been deemed effective means of behavioural change within healthcare professionals (Gordon et al. 1998). For the purpose of this review, only structured educational interventions were considered, thus reminders alone were not sufficient to comprise an educational intervention. This review found reminders in the form of both

Table 5. Percentage reduction in infection rates following intervention.

Reference	Infection rate pre-intervention (CVC days, unless specified)	Infection rate post-intervention (CVC days, unless specified)	Percentage decrease in infection	Educational group
Ahlin et al. 2006	n/a	n/a	Unable to calculate	Education, multimodal with demonstration
Costello et al. 2008	7.8/1000	2.3/1000	71	Education, multimodal with demonstration
Curchoe et al. 2002	9.9–14/1000	2.1–5.3/1000	62	Education, multimodal with demonstration
Eggimann et al. 2000	9.2/1000	3.3/1000	64	Education, multimodal with demonstration
Ely et al. 1999	Not measured	Not measured	Unable to calculate	Education, multimodal with demonstration
Harnage 2007	11 cases	0 cases	100	Education, multimodal with demonstration
Sherertz et al. 2000	4.51/1000	2.92/1000	35	Education, multimodal with demonstration
Centers for Disease Control and Prevention 2002	4.31/1000	1.36/1000	68	Education, multimodal with demonstration
Kennedy & Nightingale 2005	7.06/100 PN days	0.6/100 PN days	Unable to calculate	Education, multimodal with demonstration. Self study module
Coopersmith et al. 2004	10.8/1000	3.7/1000	66	Education, multimodal with demonstration. Self study module
Britt et al. 2007	Not measured	Not measured	Unable to calculate	Education, multimodal with simulator
Miranda et al. 2007	Not measured	Not measured	Unable to calculate	Education, multimodal with simulator
Ramakrishna et al. 2005	Not measured	Not measured	Unable to calculate	Education, multimodal with simulator
Velmahos et al. 2004	Not measured	Not measured	Unable to calculate	Education, multimodal with simulator
Frankel et al. 2005	11/1000	1.7/1000	85	Education, multimodal with video
Salemi et al. 2002	3.0/1000	1.4/1000	53	Education, multimodal with video
Schelonka et al. 2006	8.5/1000	5.5/1000	35	Education, multimodal with video
Xiao et al. 2007	Not measured	Not measured	Unable to calculate	Education, multimodal with video
Bhutta et al. 2007	8.6/1000	3.0/1000	65	Education, multimodal with video
Bjornestam et al. 2000	Not measured	Not measured	Unable to calculate	Education, multimodal without demonstration
Bishop-Kurylo 1998	12.2/1000	7/1000	43	Education, multimodal without demonstration
Hatler et al. 2006	12.8/1000	2.88/1000	78	Education, multimodal without demonstration
Higuera et al. 2005	46.3/1000 (average for control group)	19.5/1000 (average for intervention group)	Unable to calculate	Education, multimodal without demonstration
Lobo et al. 2005	20/1000	12.0/1000	40	Education, multimodal without demonstration
Pronovost et al. 2006	2.7/1000	0/1000	100	Education, multimodal without demonstration
Render et al. 2006	1.7/1000	0.4/1000	76	Education, multimodal without demonstration
Thibodeau et al. 2007	Not measured	Not measured	Unable to calculate	Education, multimodal without demonstration
Crawford et al. 2000	Not measured	Not measured	Unable to calculate	Education, multimodal without demonstration. Self study
Berenholtz et al. 2004	11.3/1000	0/1000	100	Education, multimodal without demonstration. Self study
Coopersmith et al. 2002	3.4/1000	2.8/1000	18	Education, multimodal without demonstration. Self study
Dinc & Erdil 2000	Not measured	Not measured	Unable to calculate	Education, multimodal without demonstration. Self study
McKee et al. 2008	5.2/1000	2.7/1000	48	Education, multimodal without demonstration. Self study
Tsuchida et al. 2007	4/1000	1.1/1000	73	Education, multimodal without demonstration. Self study
Warren et al. 2004	9.4/1000	5.5/1000	42	Education, multimodal without demonstration. Self study
Warren et al. 2003	4.9/1000	1.6/1000	67	Education, multimodal without demonstration. Self study
Warren et al. 2006	11.2/1000	8.9/1000	21	Education, multimodal without demonstration. Self study
Yilmaz et al. 2007	13.04/1000	7.6/1000	42	Education, multimodal without demonstration. Self study

(*continued*)

Table 5. Continued.

Reference	Infection rate pre-intervention (CVC days, unless specified)	Infection rate post-intervention (CVC days, unless specified)	Percentage decrease in infection	Educational group
Young et al. 2006	11.3/1000	3.7/1000	67	Not specified
Rosenthal et al. 2003	45.9/1000	9.9/1000	78	Not specified
Berriel-Cass et al. 2006	7/1000	3.0/1000	57	Not specified
Capretti et al. 2008	11/1000	3.1/1000	72	Not specified
Gnass et al. 2004	No baseline	Fell to 2.7/1000	Unable to calculate	Not specified
Goeschel et al. 2006	Not reported	Not reported	Unable to calculate	Not specified
Misset et al. 2004	3.5/1000	0.0/1000	100	Not specified
Price et al. 2002	4.2/100 patient months	>1/100 patient months	76	Not specified
Wall et al. 2005	7/1000	3.8/1000	46	Self study
East & Jacoby 2005	Not measured	Not measured	Unable to calculate	Self study

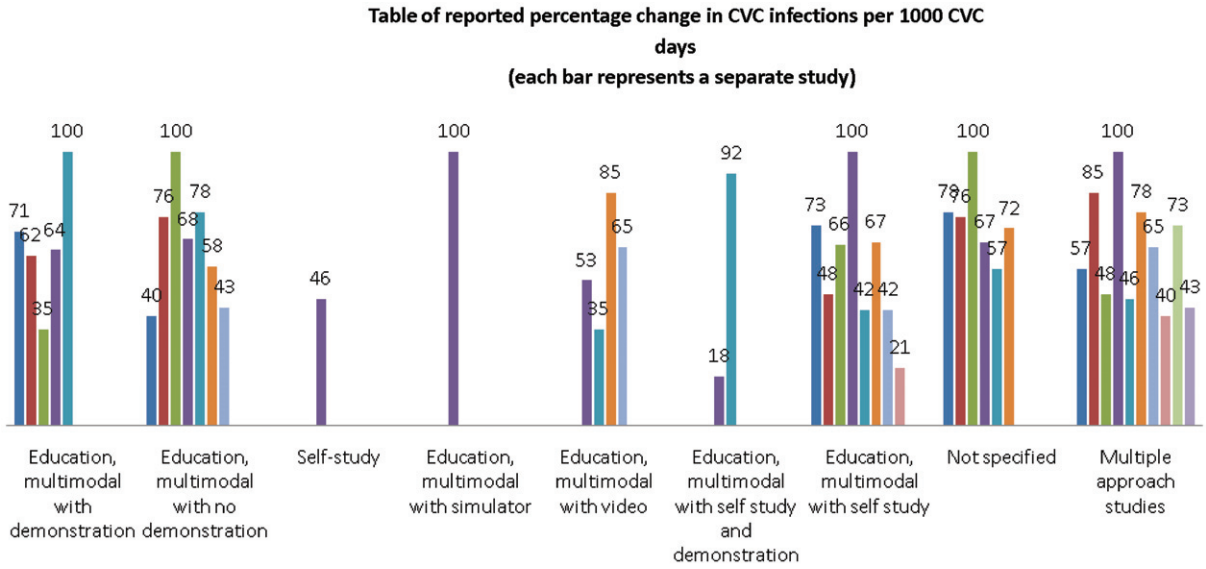

Figure 1. Table of percentage reduction in infection rates following intervention.

formal reminders: feedback (as discussed above), posters, surveillance, incentives, and checklists, and informal reminders: policy changes, informal surveillance or testing of skills. As most interventions used some form of reminder, it is difficult to identify the specific effects of these.

Few studies in this review used web-based resources as a means of delivering education. Using the Internet as a platform would be a cost-effective means of educating staff, and could provide tailored, interactive learning pathways for professional education.

It is difficult to determine what, if any features of educational intervention delivery have the greatest impact on healthcare professionals' practice and behaviour. Although reasons for behavioural change following educational delivery have been hypothesised (Bandura et al. 1977), there is no research evidence base to support this. Decisions relating to delivery of educational interventions must be based on local and practical factors, and assess needs of individuals prior to education, include enabling materials to incorporate differing learning styles and supplementary material to ensure effective course delivery (Davis et al. 1999). Clinical case examples should be present, as should an opportunity for immediate practice to cement development and retention of knowledge and skills knowledge construction rather than didactic teaching.

It cannot be determined from the evidence reviewed and presented if the intensity of educational interventions is associated with more prolonged and increased levels of compliance. Interestingly, whilst some included studies have both utilised and commented on the effects of a 'train the trainer' approach, no studies directly assessed trainee engagement in deliberate practice and the lasting effects of this on the impact of the educational intervention.

Limitations of analysis

Out of 47 studies, six were deemed to be of low quality (a quality score of below 50%). See the BEME website (www.bemecollaboration.org) for individual quality scores. Overall, methodological reporting and quality was inconsistent. The intervention implementation strategy was often poorly reported. Few studies reported sufficient detail about study design. Concealment of allocation and blinding of

professionals was also under-reported for the few studies that used control groups. Duration of follow up ranged from 1 week to 36 months, with insufficient reporting of length of follow up for numerous studies. Additionally, most studies did not provide data as to whether the intervention was mandatory or voluntary, and group size of participants was infrequently reported.

Whilst assessment of quality is a complex yet fluid concept, with no firm framework for assessment, measures were taken to ensure adequate reporting of quality using a standardised assessment tool (based on Shaw et al. (in press) and adapted from Downs & Black (1998) and Kmet et al. (2004)). Where no data was present, for example relating to group size, this was scored as 'not reported' rather than 'not present', and a quality score was calculated as a percentage to allow for as adequate a comparison between studies as possible. Despite this strategy, the factors reported above may still have lead to an under-reporting of degree of bias, and consistent variations in reporting may have prevented firm comparisons and made the drawing of conclusions difficult.

Few studies considered healthcare professionals' input in determining content and delivery of educational intervention, or evaluated knowledge and attitude change of healthcare workers. No study considered attitudes or personal values of healthcare professionals as a basis for the development of an intervention, tailored to that particular healthcare group, a factor indicated as pre-requisite for some interventions to be successful (Burgers et al. 2003; Grol et al. 1998). In a similar vein, no study assessed the motivation of healthcare workers to change as a contributing factor to the success of educational interventions, regardless of mode of delivery. It has been hypothesised that motivation alone may have a substantial effect on the success of educational interventions when the topic is of low interest to healthcare workers (Foy et al. 2002). This may explain variations in success of interventions prior to 2000, as infection control became a vested public interest after this date. Differences in motivation between participants may affect the reported results, although this will be difficult to identify. This should be taken into consideration, both when generalising the results from this review and planning future research.

Theories of behavioural change also suggest the importance of motivation in changing practice (Bandura et al. 1996), thus studies investigating educational interventions in response to an outbreak may have greater effect than those targeting day-to-day practice, due to increase in perceived seriousness of the education (Price et al. 2002).

All of these implications and limitations of analysis should be taken into consideration when interpreting this systematic review.

Implications for practice

Following this systematic review, several implications for practice have been proposed.

(1) Educational interventions appear to have the most prolonged and profound effect when used in conjunction with audit, feedback and availability of new clinical supplies consistent with the content of the education provided.
(2) Educational interventions will have a greater impact if baseline compliance to best practice is low.
(3) Repeated sessions, fed into daily practice, using practical participation (such as the use of demonstrations, video education, use of simulator or self study materials) appears to have a small, additional effect on practice change when compared to education alone.
(4) Active involvement from healthcare staff, in conjunction with provision of formal responsibilities and motivation for change, may change healthcare worker practice.
(5) Dissemination of information through peers or higher management may have a small effect on practice change.

Implications for research

Difficulties in between-study comparisons have been apparent when performing this review. In order to alleviate this problem and allow for future reviews to investigate and clarify factors relating to the effectiveness of delivery of education within healthcare, several implications for research must be taken from these findings.

Adequate group sizes are needed, with groups being large enough to measure the relatively small effects of each educational component with adequate specificity and accuracy. Reporting and performing of both allocation of concealment and adequate blinding must be implicit to allow for comparisons both within group and across studies. Sensitive, generalisable and validated measures are needed to allow for adequate determination of baseline knowledge, attitudes, motivation and behaviour of healthcare workers, and for comparisons post-intervention. Before and after measurements are required, with sufficient follow-up periods to ensure longitudinal stability in results.

Of the 47 studies considered in this review, only one used within-study comparisons of effects of differing delivery on practice (Xiao et al. 2007). More within-study comparisons of conflicting modes of educational delivery are needed, in future research.

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